Wisconsin's Electrical System Response to the August 14, 2003, Lake Erie Loop Cascading Electric System Outage

An Interim Report to Governor James Doyle and the Wisconsin Legislature

By the Public Service Commission of Wisconsin

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Introduction

On August 14, 2003, at about 4:11 p.m. EDT, major losses of electric load occurred in the northeastern United States and portions of Ontario, Canada. Electric service to about 50 million people was interrupted for from several hours to several days. The blackout did not reach into Wisconsin, although some effects of it were seen on the Wisconsin electric system. Investigations as to the cause and implications of the blackout are being conducted by a Joint U.S.–Canada Task Force, the North American Electric Reliability Council, and several states and electric utilities directly affected by the blackout.

Without attempting to predetermine the facts and circumstances leading to or causing the blackout, this report discusses, in general terms, the electric system operation in Wisconsin, the interconnected nature of the North American electric grid, oversight responsibility for system security and reliability, the effect of the August 14 outage on the Wisconsin system, and the extent of the likelihood that such a major outage could occur in Wisconsin. The report also offers some observations as to issues that should be addressed going forward pending the results of the ongoing investigations.

Discussion

Electrical Systems Description

Wisconsin

Wisconsin electric utilities own and operate approximately 12,500 megawatts (MW) of electric generating capacity in the state. They also have approximately 1,500 MW of merchant power plant capacity under contract. Some of this capacity is located outside of Wisconsin. The electric transmission system in Wisconsin is owned and operated by three utilities: American Transmission Company, LLC (ATC), which has the transmission facilities in eastern Wisconsin; and, Xcel Energy (Xcel) and Dairyland Power Cooperative (DPC), which have the transmission facilities in western Wisconsin. The Wisconsin 2003 summer peak load was forecasted at about 12,600 MW. A recent transmission assessment estimated the import capability of the Wisconsin ATC footprint to be about 900 MW from the west and about 1,650 MW from northern Illinois, with simultaneous import capability from both directions of about 1,800 MW.

The electrical power system in Wisconsin operates under the oversight of two regional reliability councils of the North American Electric Reliability Council (NERC). NERC is a not-for-profit company formed by the electric utility industry in 1968, following the 1965 New York electric system blackout, to promote the reliability of the electricity supply in North America through the voluntary use of common planning and operating guidelines. The Mid-Continent Area Power Pool (MAPP) oversees the northwest and western part of the state composed of the Xcel and DPC control areas. (A control area is a portion of the electrical system where generation is controlled to meet electrical demand (load) within that area.) Mid-America Interconnected Network, Inc. (MAIN) oversees the remainder of the state in which transmission service is provided by ATC. Control areas inside ATC's Wisconsin footprint are operated by Wisconsin

Power and Light Company (WP&L), Madison Gas and Electric Company (MGE), Wisconsin Electric Power Company (WEPCO), and Wisconsin Public Service Corporation (WPSC).

The Wisconsin transmission system has been constrained for a number of years. On the western side of the state, the Eau Claire-Arpin 345 kilovolt (kV) transmission line has operated under a daily power transfer limit of approximately 800 MW, subsequent to a 1997 incident, even though it has a thermal rating of over 1,000 MW. Load ratings for this line are checked and forecasted on an hourly basis for different dynamic power transfer limits because of the importance of the line in carrying power imports into Wisconsin from the west. This summer, under certain generation and load conditions, power flows on the line have been limited to less than 500 MW. Power flows in the southern part of the state are also constrained almost daily, with a number of lines located along the interface with Illinois from southeastern Wisconsin to southeastern Iowa being the limiting elements. Michigan's Upper Peninsula (UP) transmission system also has constraints that affect Wisconsin due to the unique geography as well as generation and load requirements. Currently, the Wisconsin-UP interface is additionally constrained pending complete restoration of two of the Presque Isle generators in Michigan, damaged in the May 2003 flood.

Midwest and to the East

The Midwest Independent System Operator (MISO), headquartered in Carmel, Indiana, is the Regional Transmission Organization (RTO) covering all or parts of 11 states in the upper Midwest and has oversight responsibilities for a peak electric demand of over 100,000 MW. As Security Coordinator, MISO has the responsibility to monitor the power flows within the control areas in its purview, and to ensure the reliability of the electric generation and transmission throughout that area. Other RTOs directly involved in the August 14 cascading power outage around Lake Erie (the Event) include: Ontario Independent Electricity Operator (IMO) – 30,000 MW; PJM Interconnection – 64,000 MW (covering parts of Pennsylvania, New Jersey and Maryland); New York ISO – 25,000 MW; ISO New England – 25,000 MW (covering states east of New York); and Hydro Quebec – 35,000 MW.

Power System Security

Planning and Design Criteria

Generation and transmission systems are designed to withstand the loss of any one element (transmission line or generator) at peak load so that the system will automatically remain intact. This is referred to as "single contingency" planning and operating criteria. Accidents and natural disasters will occur that take multiple components out of service. Under such multiple contingency situations, the electric system is designed, in accordance with NERC guidelines, to automatically isolate the failed area by disconnecting it from the rest of the system to minimize the impact of such events.

Operating Criteria

Electric system operators monitor the daily operation of the electric system to always be ready for the loss of any transmission line or generator.

MISO runs a security power flow model that constantly checks for the loss of any one transmission element. Power transfers between control areas are limited so the loss of one transmission line does not overload another line, causing the overloaded line to fail or trip out of service, thus resulting in a cascading event.

The generating plant owners in the MAPP and MAIN areas have agreements to be ready with generating reserves to cover for the loss of any one generator in their respective areas. This is accomplished within seconds with reserve generation already running (called "spinning reserves") and, further, with quick-start units that can be brought on-line within minutes.

Large Cascading Events

How They Occur

It has been said "that complex systems fail in complex ways." It usually takes several independent events to occur before a large-scale complex system, such as the Wisconsin electric grid, will fail. Predicting such large-scale events is nearly impossible. The North American interconnected electric grid provides a balance of system economics and reliability. The diversity of the network allows maintenance and repairs to be performed on transmission lines and generators throughout the off-peak load periods without compromising the security of the system. Past large cascading failures occurred because of a series of failures and/or unrecognized limitations of system capabilities. The loading of system-wide transmission lines and generators to their capacity limits increases the probability of a cascading failure because remaining reserves are unable to cope with power flow shifts. The elements of planning, system design, operating procedures, information exchange, and trained personnel constantly interact to manage the provision of electric service.

Large-scale cascading outages, like the outages of August 14, 2003 (the Event), are rare on the North American electric transmission system because of the reliability design of the system. Reliability is composed of two factors: security and availability. Security is a measure of the system to withstand a disruption and to continue without collapsing. Availability is a measure of the system to continuously supply power. System reliability can always be improved – at a cost.

Transmission line outages occur for physical reasons (e.g., lightning, wind, ice, tree contact, material failure) or for electrical reasons (e.g., breaker operation providing over-current protection.) Generation outages occur from reasons such as plant equipment failures, high or low system frequency, disconnection from load, and inability to follow rapidly changing load.

If the electric system is operated to withstand an outage of the largest generating unit or transmission line, a cascading failure should not occur with a single contingency outage. An

outage may cascade when more than one generating unit or transmission line outage occurs in a relatively short time period, such that the system load and generation in the area can not be balanced given the remaining transmission system availability. The magnitude of the load/generation imbalance and the duration of the time period over which the imbalance occurs will determine the extent to which the outage will cascade. (The greater the imbalance and the shorter the duration, the greater the likelihood of a larger-scale cascading outage.) Greater generation imports into or exports from an area will increase the magnitude of a load/generation imbalance under multiple contingency outages, and may lead to a larger-scale cascading outage.

History

Prior to the Event, large-scale cascading outages in North America have occurred in 1965 and 1977 (New York area blackouts), and in 1996 (California area blackouts.) Closer to Wisconsin, the MAPP to MAIN interface separated in 1998 with the unexpected outage of the King-Eau Claire 345 kV line while attempts were being made to restore service on the Prairie Island-Byron 345 kV line that had already tripped out of service earlier that day. When that event occurred, the Wisconsin electric system remained intact, while parts of northern MAPP and northwest Ontario suffered blackouts.

The August 14, 2003, Lake Erie Loop Collapse (the Event)

Overview of the Event

Starting at about 4:11 p.m. EDT on August 14, major losses of electric load occurred in the northeastern U.S. and Canada. The areas most affected included lower-Michigan, Ohio, New York City, Ontario, Quebec, northern New Jersey, Massachusetts, and Connecticut. About 62,000 MW of load was lost affecting about 50 million people. Restoration of service began immediately upon conclusion of the outage with about 75 percent of service restored by the following morning and total restoration taking several days.

Investigations

Immediately following the Event, NERC, in conjunction with its regional reliability councils and member utilities, began an investigation into the causes of the outage. Subsequently, President Bush and Prime Minister Chretien appointed a U.S.-Canada Joint Task Force (Task Force), co-chaired by Secretary of Energy Spencer Abraham and Canada's Minister of Natural Resources Herb Dhaliwal, to identify the causes of the outage and to seek solutions to help prevent future outages. The findings of NERC's investigation are expected to supplement and contribute to the work of the Task Force, as will separate investigations being conducted by several states and the Province of Ontario. Further, Congressman Tauzin, Chairman of the U.S. House of Representatives Committee on Energy and Commerce, has begun hearings on the matter which are ongoing at this time.

To avoid speculation and diversion from the goal of identifying all factors contributing to the Event, the Task Force has indicated that it will only release comprehensive and confirmed data

during its investigation. The Task Force is making a root cause analysis to determine all factors contributing to the Event. Its investigation will focus on the timing of the physical events, all planned and unplanned precursor events, communication, and processes. The first report of the Task Force is expected in several weeks.

Sequence of Events

This report is not intended to make conclusions as to the cause of the Event. However, for purposes of understanding the nature of what happened to the electric system in the affected area, following is a general chronology of the sequence of generating plant and transmission line outages and power flow shifts that occurred. This information was compiled from publicly-available information, primarily from reports from International Transmission Company (ITC), which provides transmission service in the Detroit area, and from reports by the Associated Press. It is important to note that this information has not yet been verified.

The events listed below are shown relative to 4:10:46 p.m. EDT, the time of the rapid cascading outages of generating plants and transmission lines directly resulting in the widespread blackout.

Prior Conditions

Time (T) minus 1:05:00 (one hour and five minutes)

- First Energy (FE) 750 MW Davis Besse nuclear plant continues long-standing maintenance outage
- 550 MW FE Eastlake generating unit in northern Ohio goes off-line at 2:00 p.m.
- Chamberlain-Harding transmission line into Cleveland goes out of service
- Power flows across Michigan are normal

25 minutes later – T minus 0:39:00

- Second line feeding Cleveland (Hanna-Jupiter) goes out of service
- Low voltage detected around Cleveland
- Michigan interface flows remain steady

10-15 minutes later – T minus 0:25:00

- Two more lines in northern Ohio (Star-South Canton and Tidd-Canton Central) go out of service
- Cleveland experiences severe low voltages
- Michigan flows remain steady

20 minutes later – T minus 0:05:00

- The line feeding northern Ohio (Sammis-Star) goes out of service
- Flows on the ITC – FE connection reverse and FE draws 200 MW through Michigan

3 minutes later – T minus 0:02:00

- Two more lines feeding northern Ohio (E. Lima-Fostoria and Muskingum-OH Central) go out of service
- Northern Ohio now isolated electrically from the rest of Ohio
- FE now draws 2,200 MW through Michigan
- Flows on the ITC-IMO international line reverse by 700 MW
- Michigan voltage begins to decline

30-40 seconds later – T minus 0:01:29

- With the declining voltage, two Mid-Michigan power plants (Kinder-Morgan and MCV) totaling 1,800 MW go off-line within 15 seconds of each other
- Michigan voltage begins to collapse

1 minute later – Time minus 0:00:30

- ITC system in voltage collapse with 30 transmission lines going out of service in less than eight seconds (and according to design)
- ITC separates electrically from the rest of Michigan
- FE still is pulling power through ITC from IMO at 2,800 MW from Ontario and New York

Blackout Sequence

Seconds later – T minus 0:00:00 (Eastern Daylight Time 4:10:46 pm)

- 12 generating units in Michigan go off-line
- Ontario tries to support Michigan and Ohio for two minutes

One minute later – T plus 0:01:00 (approximately)

- Several Ohio generating units and transmission lines trip off-line
- Several New York generating units trip off-line

Two minutes later – T plus 0:02:00 (approximately)

- Ontario generating units trip off-line
- More NY generating units trip off-line

(The timing of the events after the cascading started is difficult to determine due to the independent reporting sources.)

Wisconsin's System Responses

Description of Response

To assess the impact of the Event on the Wisconsin electric grid, the Commission compiled information from the state's major electric providers (ATC, WEPCO, WP&L, WPSC, Northern States Power Company of Wisconsin, MGE and DPC) as to:

- The operating status of generating units and transmission lines immediately before, during and after the Event;
- System frequency and voltage level deviations, and power flow shifts that occurred at the time of the Event;
- The impact on each utility's system capacity and energy purchases, and on the ability to make such purchases; and,
- The status of each utility's provision of capacity and/or energy to assist the utilities directly affected by the Event.

Following is a summary of that information:

Generation Status

The utilities reported that, with one exception, the generating plants on-line just before the Event stayed on-line during and after the Event. An increase in system frequency, from a normal operating level of 60 Hz (cycles per second) to about 60.24 Hz (significantly higher than deviations seen during normal operating conditions), occurred system-wide at the time of the Event. Only minor voltage level variations occurred across the Wisconsin system.

Normal system response to a system frequency increase is for the generating units to speed up in proportion to the rise in frequency. The data shows that is what occurred at the time of the Event. Control systems at the generating plants responded as designed to reduce the output of the units and to stabilize the system frequency and voltage levels.

The Edgewater Unit 4 340 MW generator in Sheboygan was the only generator that tripped off-line at the time of the Event. The outage of this unit is attributed to higher-than-normal back-pressure in the furnace due to ash buildup on the air heater. According to WP&L, the primary owner and operating partner for the Edgewater units, air-heater ash buildup is normal for Edgewater Unit 4, is cleaned routinely, and typically does not present a problem during normal load demand. However, rapid load swings at the time of the Event, along with the higher-than-normal back-pressure in the furnace caused the unit to trip from high furnace pressure. WP&L indicated that improvements are planned for 2004 to eliminate the ash buildup condition.

Transmission Status

ATC reported that only two transmission lines (both of which are 138 kV lines in the Milwaukee area) were out of service for maintenance at the time of the Event. Further, operating constraints for transmission line loading relief (curtailment or restriction on transmission transactions) were

in effect for only two areas in northeastern Wisconsin. DPC reported one scheduled outage of a 161 kV transmission line that day and only one constraint causing transmission line loading relief, neither of which appeared related to the Event.

Prior to the Event, net power flows were into the ATC system from the Commonwealth Edison (ComEd) system from the south, from the Xcel and DPC systems from the west, and from the Michigan Electric Transmission Company (METC) system from lower Michigan into upper Michigan. Just prior to the Event, imports from ComEd substantially increased, and flows reversed and substantially increased into the Xcel system to the west. Power flow on the Eau Claire-Arpin 345 kV line reversed by about 380 MW. At the time of the Event, flows from ComEd further increased substantially, imports from lower Michigan and from the DPC system increased, and flows from eastern Wisconsin into the Xcel system decreased somewhat. Despite these major power flow shifts, no transmission lines tripped out of service as a result of the Event.

Electric Service Outages

Electricity demand levels on August 14 were significantly lower than projected summer peak demands given the moderate temperatures at that time. The electric utilities in Wisconsin had available generation operating reserves well in excess of required levels and, as indicated above, transmission system constraints were minimal. No loss of electric service to Wisconsin customers occurred as a result of the Event.

Impact on System Capacity and Energy Purchases

The utilities reported that the Event had no impact on their transactions to purchase energy and capacity from outside of their respective areas. Existing transmission system constraints generally restrict non-firm energy purchases (non-firm transactions are typically made for economic reasons but have limited or no assured availability.) Such transmission limitations are not unusual and were not considered to be caused by the Event.

Most of the utilities also reported that they had generation reserves available for assisting the utilities affected by the Event; however, no reserve-sharing requests were made as a result of the Event.

Ability of the Wisconsin System to Withstand a Major Cascading Outage or to Recover if It Occurs

The Wisconsin electric system is part of North America's "Eastern Interconnection," a large integrated power system with great resilience to provide support during severe electric power system disturbances. It is designed and operated according to NERC guidelines to withstand "single contingency" outages of a large generating unit or transmission line so that the remainder of the system will not fail. Multiple contingency outages occurring simultaneously or in short-duration sequence would be expected to have wider consequences. There can be no absolute guarantee that the Wisconsin system would withstand a major disturbance originating outside the state given the interconnected nature of the grid; however, the risk of such an event is the basis for some of the limits placed on Wisconsin energy imports under NERC operational guidelines.

Improved protection from major system outages can be achieved by continuing to strengthen the transmission system in Wisconsin with prudent investment in transmission facilities both within and around the area, and prudent investment in generation to ensure an appropriate balance.

If a widespread system outage were to occur in Wisconsin, all of the utilities are prepared to restore service expeditiously using "System Black-Start Restoration" plans. System restoration is a coordinated effort between ATC and the control area operators to use blackstart-capable generators to energize the grid, start other generators, deliver power to loads, and resynchronize interconnections. These plans generally provide for isolating small areas of the grid, using gas-fired combustion turbines, or other generating facilities that can be operated without system power, to provide station power to start the larger local generating units and critical substations. Service can then be restored to the backbone transmission system and to critical loads within each isolated area. Once that is accomplished, service between the isolated areas can be synchronized and reestablished, thus leading to full restoration. Throughout the restoration process, the utilities would establish and maintain close communications with state and local authorities as to the extent of any damage to facilities, the effect on the provision of service to customers and the status of recovery efforts.

Observations

The electric system in Wisconsin felt the impact of the Event in the form of significant power flow shifts and a system frequency increase, but withstood that impact. The forced outage of one large generating unit was covered with available reserves and the system was stabilized with no further outages or loss of service. It appears the system operated as designed; however, no conclusions can be reached at this time as to whether the system would have held under higher load conditions.

Although no immediate action appears warranted as to the operation of the Wisconsin system, the Commission will need to closely monitor the investigations being conducted by the Task Force and NERC. When results of those investigations become available, the Wisconsin system can be further evaluated and any need for action determined at that time.

One of the likely issues to be debated in the context of the Event is whether the NERC security and reliability voluntary operating guidelines remain appropriate, whether any changes to those guidelines are necessary, and whether mandatory, enforceable operating requirements should be promulgated, either at the federal or state level. Given the interconnected nature of the electric grid, differing state-by-state reliability and security standards would be impractical, if not impossible, to administer. Accordingly, the discussion will likely focus on whether the existing guidelines should be made mandatory and, if so, what organization should be given the oversight and enforcement responsibility. The Task Force and NERC investigations should provide insight into this issue. The Commission will need to consider their findings and determine appropriate action to take at that time.

There is no guarantee against a widespread outage occurring in Wisconsin. However, improvements to the transmission and generation system would, no doubt, strengthen the ability of the system to withstand such an event. Necessary system improvements are matters for the Commission to address, in the short term, through pending and expected applications by Wisconsin utilities for authority to construct facilities. There are several major transmission and generation project applications pending before the Commission at this time. Several more are expected within the year. For the longer term, the Commission will address this in the context of the expanded Statewide Energy Assessment planning initiative, begun earlier this year at the direction of Governor Doyle. The Commission's first report on this initiative is expected by early 2004.

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